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Science opportunities with a double Langmuir probe and electric field experiment for JIMO

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Abstract

The three icy Galilean moons of Jupiter: Callisto, Ganymede, and Europa, offer a range of exciting science opportunities for space physics and aeronomy. They all have thin atmospheres with residence times of a few days at most. The surface interactions with the space environment determine the atmospheric and ionospheric properties. The Jupiter Icy Moons Orbiter (JIMO) gives possibilities to investigate the weathering properties of their surfaces and volatile material expelled from their interiors. The atmospheres and the ionized ionospheric components of the Galilean moons (including the volcanic moon Io) interact strongly with the co-rotating magnetosphere of Jupiter. This interaction is dynamic and for example triggers energy transfer processes that give rise to auroral signatures at Jupiter. The icy moon's ionospheres are likewise highly variable in time and estimated peak electron densities vary between 1000 and 20,000 cm^{-3} near their surfaces. A particularly interesting interaction occurs between the magnetosphere of Jupiter and the mini-magnetosphere of Ganymede and its ionosphere. A double-Langmuir probe (LP) experiment orbiting the moons at a short distance for several months will give valuable insight into these processes. Foremost the LP measures in situ plasma density and temperatures of the ionospheric components of the moons with high time resolution and thereby provides estimates of key parameters for the dynamical behaviour of surface weathering and magnetospheric influences. In addition many other physical parameters important to the dynamics of these systems can be estimated with such an instrument, like the plasma flow and the DC electric field. Recent results from the LP part of the Radio and Plasma Wave Science (RPWS) on board the Cassini/Huygens spacecraft orbiting Saturn show that an LP works in extended plasma parameter domains with very good science return.
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1. Introduction

In this paper we outline the principles behind a double Langmuir probe instrument and give examples of science issues that can be addressed by this type of instrument in the Jupiter moons environment. We only briefly mention engineering details, and instead illustrate the science capabilities by showing examples of investigations from related instruments on board other spacecraft.

2. Basic properties of the icy moons atmospheres and ionospheres

The atmospheres of the three icy Galilean moons of Jupiter are almost collision-free, and the atoms and molecules within them can to a large degree directly leave

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the weak gravitational field of these moons. The residence times for their atmospheres are of the order of a few days at most. These atmospheres can therefore rightly be termed exospheres, and their corresponding ionized parts can be termed exo-ionospheres. Observations indicate that the exospheres of these three objects (Europa, Ganymede and Callisto) are oxygen rich (e.g. Hall et al., 1995, 1998). They have also been modelled by several authors (e.g., Saur et al., 1998; Eviatar et al., 2001; Johnson, 2002; and references therein), and the oxygen was thought to be water products released from the surface by the action of magnetospheric energetic charged particle bombardment. The magnetospheric ions come to a large degree from the Io plasma torus. Alkali atoms have been detected in the exosphere of Europa (Brown and Hill, 1996), which has been suggested to come from sub-surface oceanic material that has breached the icy surface in the past (Pappalardo et al., 1999). All the three icy moons are predicted to have sub-surface oceans (Khurana et al., 1998). Other possibly contributing atmospheric sources are diffusion from the interior, meteorite impact evaporation and solar radiation decomposition and sputtering. The exosphere of Callisto may also harbour significant amounts of CO_2 as detected by the NIMS instrument on board Galileo (Carlson, 1999).

The ionospheres of the three icy Galilean moons have been observed with radio occultation techniques (e.g. Kliore et al., 1997, 2002) as well as by using in situ upper hybrid emission measurements (e.g. Gurnett et al., 2000) from the Galileo spacecraft. On Callisto peak ionospheric densities of up to 17,000 cm^{-3} were inferred a few tens of km above the surface near the equator. The Callisto ionosphere seemed highly variable in time (between flybys) and a detectable ionosphere was only found when the ram-side was in sunlight, which indicate that both plasma impact ionization and photo-ionization are sources for this ionosphere. The ionosphere of Europa showed peak densities up to 10,000 cm^{-3} near the surface.

The ionosphere of Ganymede is a special case since this moon also has a substantial internally generated magnetic field that forms a small magnetosphere inside the magnetosphere of Jupiter. The presence of a magnetic field affects the dynamics of the ionosphere (Kivelson et al., 1996; Gurnett et al., 1996). The ionosphere is dominated by molecular oxygen ions at polar latitudes and by atomic oxygen ions at low latitudes (Eviatar et al., 2001). Protons were absent at all latitudes. The polar wind plasma outflow along "open" polar cap field lines would likely consist of atomic oxygen ions because of their greater mobility. Note that open field lines here refer to field lines not immediately returning to the moon. However, because of Ganymede's location deep inside the Jovian magnetosphere, its open field lines connect to the Jovian main field rather than to the interplanetary magnetic field. Khurana et al. (submitted manuscript; also in Kivelson, 2004) suggest that the ice properties are modified by the impacts of the energetic particles entering on polar cap (open) field lines.

3. Dynamic interaction with the Jovian magnetosphere

The three icy Galilean moons of Jupiter: Callisto, Ganymede, and Europa, all orbit Jupiter well inside the Jovian magnetopause and, consequently, interact primarily with Jupiter's co-rotating magnetosphere. In contrast to the solar wind flow that interacts with Jupiter, the interaction at the Galilean moons is sub-magnetosonic or possibly trans-magnetosonic. All three of the moons have orbital velocities that are lower than the co-rotation velocity of Jupiter's magnetosphere and, thus, interact with the Jovian magnetospheric plasma as it overtakes the moons from the trailing side. Because of the sub-magnetosonic nature of the plasma flow, the flow is diverted gradually without shock fronts forming. At Callisto, the Mach number may at times exceed unity, although Galileo observed no such cases (Kivelson, 2004).

The interaction of the Jovian magnetospheric plasma with the icy moons acts as a dynamo, driving field-aligned currents along Jupiter's magnetic field that close in the Jovian ionosphere. The effect is clearly seen in HST images of UV emissions from Jupiter's ionosphere at the subauroral foot points of the Galilean moons (Clarke et al., 2002).

Because of gravity and centrifugal acceleration, the Jovian magnetospheric plasma is dense at low altitude and close to the equatorial plane but quite tenuous elsewhere. Thus, the parallel conductivity along the flux tubes connecting the moons with the Jovian ionosphere is low and parallel electric fields may need to develop to sustain the current flow. Also, the Alfvén velocity in this region is high, with possibly steep gradients both close to the planet and close to the equatorial plane where dense ionospheric plasma escapes from the moons. These regions may therefore be prone to generate dispersive Alfvén waves and related low frequency plasma waves, which in turn transport energy to other parts of the magnetosphere.

Ganymede, surprisingly, has an intrinsic magnetic moment corresponding to an equatorial surface field of about 700 nT. The dipole moment is aligned with the Jovian magnetic field and, thus, the interaction at Ganymede's magnetopause favours reconnection steadily, as opposed to the interaction between a planet and the solar wind that depends strongly on the instantaneous orientation of the interplanetary magnetic field.

Callisto and Europa do not have significant permanent magnetisation. Rather, an induced magnetic field is set up through the interaction with Jupiter's planetary field. Because of the Jovian dipole tilt the induced fields at the moons vary at the synodic period of Jupiter, with the dominant field variation being seen in the radial component. A more thorough overview of the moons and their interaction with the Jovian magnetosphere is found in, for example, Kivelson (2004).

The plasma in the Jovian magnetosphere approximately co-rotates with the planet. However, as can be seen in Table 1, the co-rotation is not perfect, but rather the plasma lags behind co-rotation by a rate that increases with distance from the planet. At all four Galilean moons the co-rotation velocity exceeds the orbital velocity of the moon and thus the moons interact with plasma catching up from the trailing side. At Ganymede, which has an intrinsic magnetic moment, the interaction is similar to that of the interaction of the solar wind with a magnetised planet with three significant exceptions. Firstly, the flow is sub-magnetosonic, and thus no shock front is formed. Secondly, the flow velocity remains relatively stable, in contrast to the fluctuating solar wind flow. Thirdly, the moon is embedded in the quasi-steady magnetic field of Jupiter rather than in the rapidly changing interplanetary magnetic field. Because of the 10° tilt of the Jovian magnetic axis with respect to its rotation axis there is a diurnal variation of the field at Ganymede at the synodic period. However, overall the field remains in an orientation favouring reconnection at all times.

The large-scale convective plasma flow in the Jovian magnetosphere and its deviation from co-rotation as well as the plasma flow associated with the (quasi-steady) reconnection at Ganymede are highly interesting to study and can be readily measured with a double-probe instrument on JIMO. At times, also the reconnection flow resulting from the solar wind's interaction with Jupiter could be studied.

Electrical current circuits are set up along the flux tubes linking the Galilean moons to Jupiter. Here the ionospheres of the moons act as MHD dynamos, which drives the power that dissipates in the Jovian ionosphere. In these flux tubes away from the equatorial plane this power transfer process is probably associated with parallel electric fields arising in the tenuous, poorly conducting, plasma there. Experimental evidence for the existence of these parallel fields is found in HST ultraviolet images that show auroral emissions from the magnetic foot points of the moons (Clarke et al., 2002). The parallel electric fields are difficult to measure directly, particularly in dilute plasmas. However, the associated perpendicular "closure fields" should be observable with a double-probe instrument.

4. ULF pulsations

ULF pulsations have been observed at Jupiter (e.g., Khurana and Kivelson, 1989) with periods in the range 10–20 min. Because of the size of the Jovian magnetosphere the eigenperiods of field line oscillations are of the order of hours (e.g., Glassmeier et al., 1989) and thus comparable to the rotation period of Jupiter. For this reason stable global oscillations are unlikely to occur. Likely, the oscillations observed are local standing waves, being reflected or dissipated at steep gradients in the Alfvén velocity (steep density gradients) rather than at the "ends" of the field lines. Similar Alfvén wave dissipation mechanisms have been observed on auroral magnetic field lines near Earth (e.g., Chmyrev et al., 1989; Boehm et al., 1990; Louarn et al., 1994; Wahlund et al., 1994).

Whatever the reflection mechanism, these waves can carry energy and momentum over large distances, unless the reflection is perfect. Thus, these transverse Alfvén waves are likely to play a role in the energetics and dynamics of the Jovian magnetosphere as well as of the plasma environments of the Galilean moons. Measuring

Table 1
A few key properties, of importance for the plasma environment near the Galilean moons of Jupiter

Body	Io	Europa	Ganymede	Callisto
Radius (km)	1815	1565	2640	2420
Distance from Jupiter (R_j)	5.9	9.4	15.0	26.4
Orbital period (days)	1.8	3.6	7.2	16.7
Relative co-rotation velocity (km/s)	45–57	84	127	228
N_e, Jovian magnetosphere (cm^{-3})	4000	50	4	0.2
Co-rotational dynamic pressure (nPa)	400	12	2	0.4
Average Ionospheric T_e (eV)	4	43	130	130
Average Ionospheric T_i (eV)	43	52	60	86
Ionospheric thermal pressure (nPa)	30	0.8	0.1	0.01
Jovian magnetic field (nT)	1800	450	100	10
Intrinsic B field (eq. surface, nT)	1300?	Small	700	Small
Alfvén velocity (km/s)	130	300	250	300
Acoustic velocity (km/s)	19	26	37	40
Magnetosonic velocity (km/s)	133	310	250	300

Adapted after Russell (2000).

Table 2
Expected LF electric field amplitudes and frequencies

Body	Europa	Ganymede	Callisto
$\|\mathbf{v}\times\boldsymbol{B}\|$ (mV/m)	38	13	2
Electron gyro frequency (kHz)	13	3	0.3
Plasma frequency (kHz)	63	18	4

the electric field in these pulsations in addition to the magnetic field is an important diagnostic tool.

4.1. Low frequency plasma wave processes

The Jovian magnetosphere picks up ions at the Galilean moons. The neutral atoms surrounding the moons can be ionized through photo ionization, electron impact ionization, and charge exchange. The processes differ in that ionization adds charges to the plasma and, thus, increases the plasma density, whereas charge exchange does not affect the plasma density. Both processes, however, add charges to the flowing plasma requiring that momentum be extracted from the flow and added to the "new" ions. Momentum transfer primarily takes place in the plane perpendicular to the magnetic field, resulting in an anisotropic particle distribution that may, in turn, result in wave generation and energy transfer. Ion cyclotron waves have been observed near, for example, Europa (e.g., Volwerk et al., 2001; Blanco-Cano, 2004). Observed frequencies include the gyro frequencies of O_2^+, Na^+, Ca^+, and Cl^+, around 1 Hz. We expect that many more plasma wave processes occur as a result of the dynamic interaction between the co-rotating magnetosphere of Jupiter with the moons ionospheric plasma. A range of other plasma wave processes was also observed near the icy moons by the Galileo spacecraft (e.g., Kurth et al., 2001a).

4.2. Expected DC electric field amplitudes and LF wave frequencies

Table 2 shows estimates of the DC electric field expected in the frame of the moons because of the Jovian magnetic field and the motion of the plasma in Jupiter's magnetosphere with respect to the moons. It also shows estimates of the plasma frequency and the electron gyro frequency in the vicinity of the moons, based on the average Jovian magnetic field and plasma density. Gyro frequencies of relevant ions are four orders of magnitude lower. Close to the surfaces of the moons the plasma density, and thus the plasma frequency, may be significantly higher due to the presence of their ionospheres. All numbers are based on the general parameters of the Jovian system given in Table 1.

Large spatial as well as temporal variations can be expected, particularly close to the moons. However, it is highly likely that an instrument capable of measuring the electric field in the range a few hundred mV/m with a resolution of a fraction of 0.1 mV/m and in a frequency range from DC up to a MHz would be able to address all relevant objectives in the Jovian system. Such an instrument can be realised with a total mass of the order 1.5–2 kg on a spinning platform, as discussed in a later section of this paper.

5. A double Langmuir probe instrument for JIMO

A double Langmuir probe experiment consists of two small conducting spherical sensors of a few cm

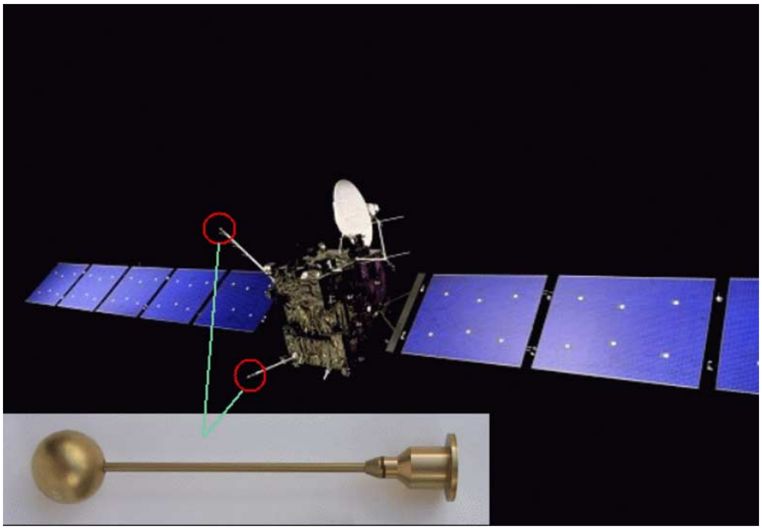


Fig. 1. The dual Langmuir probe instrument now on board Rosetta that will arrive at a comet in 2014. A similar setup is considered for JIMO.

diameter mounted on booms extending from the spacecraft. The length of the booms should optimally be longer than the local Debye length (λ_{De}) and the probes situated in the ram plasma flow. In practice, the boom length and placement is often subject to considerations of what is technically feasible on the spacecraft. On Cassini and Astrid-2 the boom length used was 1.5 m (solid booms), whereas on Cluster it was 40 m (wire booms). The Swedish Institute of Space Physics and the Alfvén Laboratory have employed a number of successful boom designs over the years. The further the sensor probes are from the spacecraft the better the sensitivity of the measurements. The total mass of the instrument is 1–2 kg (depending mostly on boom design).

A Langmuir probe is in theory a simple experiment, where the probes are set to a specific bias potential (or swept in bias potential) and the electrical current from the surrounding plasma is sampled. When the probe is negatively biased the current is dominated by ions attracted to the probe or by photoelectrons emitted from a sunlit probe. When the probe is positively biased attracted electrons dominate the current. From a controlled Langmuir probe experiment it is possible to derive a fair range of information from the cold plasma component (below an energy a few tens of eV) as described below (see Fig. 1).

The surface coating of sensors for density and electric field measurements in space must satisfy many requirements. It must be durable to sputtering, micrometeorites, and manufacturing procedures. It must also be inert to the reactive oxygen radicals encountered around the icy moons, and it should have good electrical and thermal properties in order to give a sensitive measurement and to keep the probe at a reasonable temperature.

The electrical work function, adhesion and thermal stability properties have been extensively tested in the laboratory for TiN-surface coating (Veszelei and Veszelei, 1993; Wahlström et al., 1992) as well as for other coatings (Larsson and Wahlund, 2004) which have been or will soon be used for Langmuir probe sensors. The TiN coating was applied to both the Cassini (Kurth et al., 2001b) and Astrid-2 Langmuir sensors (Holback et al., 2001) with excellent performance. See some of the results below. On BepiColombo we consider a $Ti_xAl_yN_z$ chemically deposited surface (Brogren et al., 2000) with better thermal properties in the hot Mercury environment, but otherwise very similar to the TiN surface. In the environment of the moons of Jupiter the high-energy particles in Jupiters radiation belts is of concern. However, the mechanically very hard, durable and chemically inert TiN surface is well adapted for such a radiation environment. Radiation hardened electronics components are now also available commercially.

6. Main scientific objectives for a double Langmuir probe on JIMO

- Investigate the thermal states and origins of the ionospheres (and atmospheres) of the three icy moons.
- Investigate the electrodynamic interaction between the co-rotating magnetosphere of Jupiter and the ionized parts of the three icy moons.
- Determine the conductivities of the sub-surface oceans of the three icy moons by measuring the DC electric field perturbations induced in a sub-surface ocean by the co-rotating magnetosphere of Jupiter.

Instrument mode	Measured quantity	Range
Potential sweep (each 10 s)	n_e	$0.1–10^6$ cm^{-3}
	T_e, $v_{th,i} \sim \sqrt{T_i/m_i}$	0.01–200 eV
	ϕ_{SC}	± 50 V
	UV intensity	
$\delta n/n$, interferometer	n_e, $\delta n/n$	$0.1–10^6$ cm^{-3}, <10 kHz*
	T_e	0.01–200 eV, <10 kHz *
	v_{plasma}	<100 km/s**
	Coherence length of waves	
Electric field (Given numbers assume long wire booms. See text.)	E (Components depends onprobe configuration)	Max 1 V/m
Res. ~ 0.02 mV/m		
		DC – 3 MHz

Depending on sampling frequency and probe separation.
*Depending on plasma density. Lower if density falls below 1000 cm^{-3}.
**Depending on sampling frequency and probe separation.

7. Instrument capabilities

7.1. Instrument heritage

The double Langmuir probe instrument suggested here is descended from the RPC-LAP instrument on Rosetta (Boström et al., 2004; Trotignon et al., 1999), the RPWS LP on board Cassini/Huygens (Gurnett et al., 2004) and similar instruments on several Swedish spacecraft (e.g. Viking, Freja, and Astrid-2). The electric field instrument capability is partially descended from the EFW instrument on board Cluster (Gustafsson et al., 2001), the MEFISTO instrument proposed for BepiColombo (Blomberg et al., 2004a) and similar instruments on board several Swedish spacecraft (see Fig. 2).

7.2. Basic plasma parameters

The bulk ion and electron temperatures, density, and composition are crucial parameters for understanding any space plasma and related aeronomy. For instance, knowing the plasma density and temperatures is necessary to understand what chemical pathways occur in an ionosphere/atmosphere. The plasma in the ionospheres of the icy moons as well as the surrounding magnetosphere of Jupiter is typically collision-free (mean free path $\gg \lambda_{De}$) and of low density ($\lambda_{De} \gg$ probe radius), and therefore Orbit Motion Limited (OML) theory (Mott-Smith and Langmuir, 1926) works well to describe the current-voltage relationship of a Langmuir probe in this environment. An example is shown in Fig. 3 for the dense ionospheric plasma near Earth.

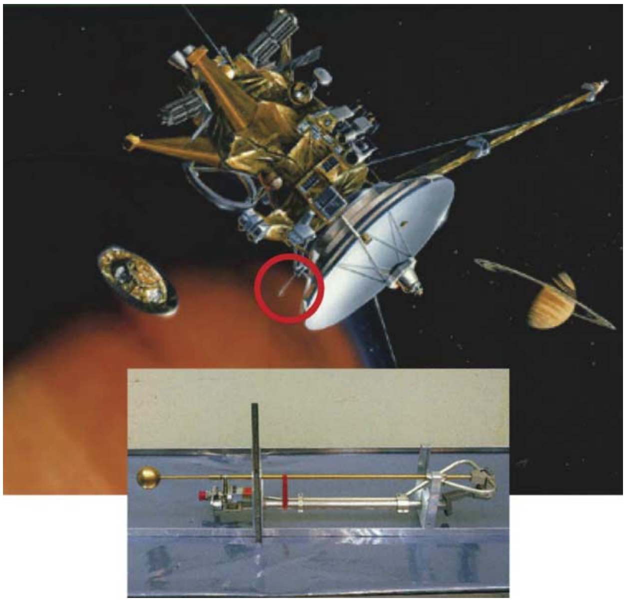
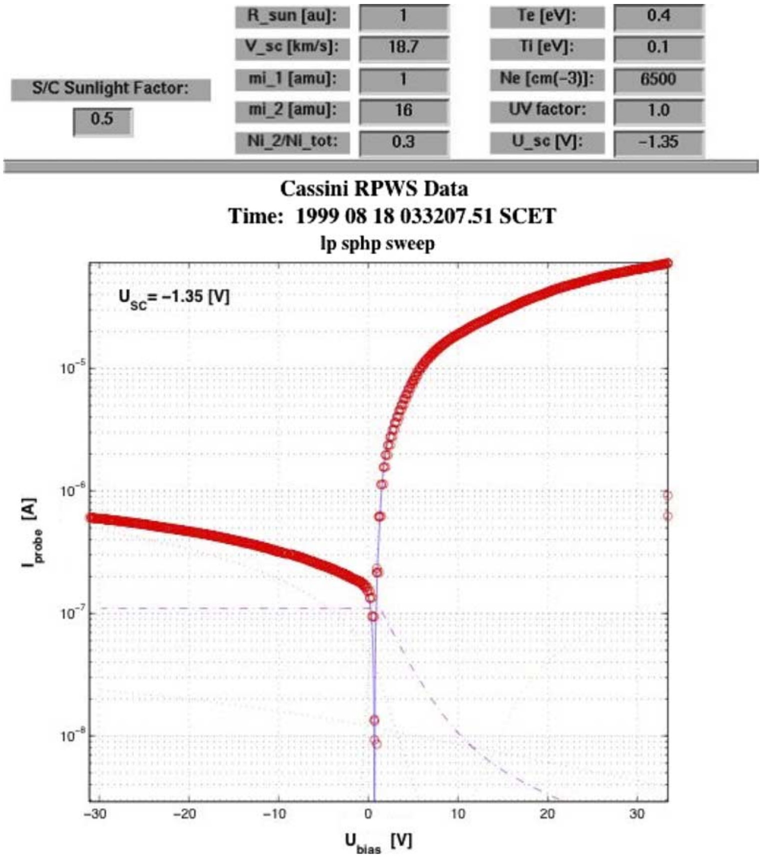


Fig. 2. The RPWS Langmuir probe on board Cassini operates successfully in most regions of the Kronian magnetosphere even if its main objective is to carry out measurements in the ionosphere/upper atmosphere of Titan.



S/C Sunlight Factor: 0.5

R_sun [au]: 1
V_sc [km/s]: 18.7
mi_1 [amu]: 1
mi_2 [amu]: 16
Ni_2/Ni_tot: 0.3

Te [eV]: 0.4
Ti [eV]: 0.1
Ne [cm(-3)]: 6500
UV factor: 1.0
U_sc [V]: -1.35

Fig. 3. An example of a Cassini RPWS Langmuir probe potential sweep during the Earth flyby at an altitude of 1200 km. The data (red rings) and model fit (blue line) show excellent agreement.

In OML theory the current for positive bias potential is directly proportional to density and the slope of the characteristic of the current–voltage relationship is proportional to n_e/T_e. From these relations the plasma density and electron temperature can be determined from a sweep. From the negatively biased part of the characteristic one can, for a dense enough plasma, estimate an effective ion energy consisting of a ram and a thermal part ($m_i v^2/2e + T_i$). Knowing the spacecraft velocity this information gives an estimate of $\sqrt{T_i/m_i}$, and by knowing the ion mass from, for example, ion mass spectrometers the ion temperature can be derived. Conversely, if the ram flow dominates, some information on the ion mass can be obtained. The negatively biased part of the Langmuir probe voltage sweeps also give information on the Ly-alpha UV intensity, which is an important parameter for determining the surface–radiation interaction processes of the icy moons of Jupiter (Brace, 1998; Mahajan et al., 1998) (see Fig. 4).

7.3. High time resolution $\delta n/n$ and T_e

On previous spacecraft, Langmuir probes at constant bias have traditionally determined the density with high time resolution (using a calibration factor and the probe current sampled at a rather high rate), while the temperature was usually determined from Langmuir probe potential sweeps every few minutes. The relative plasma density change (δn/n) is commonly sampled at kHz rate, and by careful calibration and by the use of receivers with large dynamic range (18 bit or higher), it is today possible to sample the absolute plasma density (n_e) with a similar rate. This technique was used successfully on the Astrid-2 mission (Holback et al., 2001).

Sampling of the electron temperature with second to millisecond resolution with a semi-active technique gives several orders of magnitude higher resolution in time and space as compared to a bias sweep (Raitt and Thompson, 1998; Siefring et al., 1998). A digital waveform generator is used to make an harmonic variation of the otherwise constant bias voltage and facilitates the high time resolution temperature measurement. In the ionospheres of the icy moons millisecond time resolution correspond to a distance of only a few meters along the spacecraft trajectory. This opens the possibility to study small-scale heating processes, which are believed to exist near the dynamic boundaries of the ionospheres of the moons and their

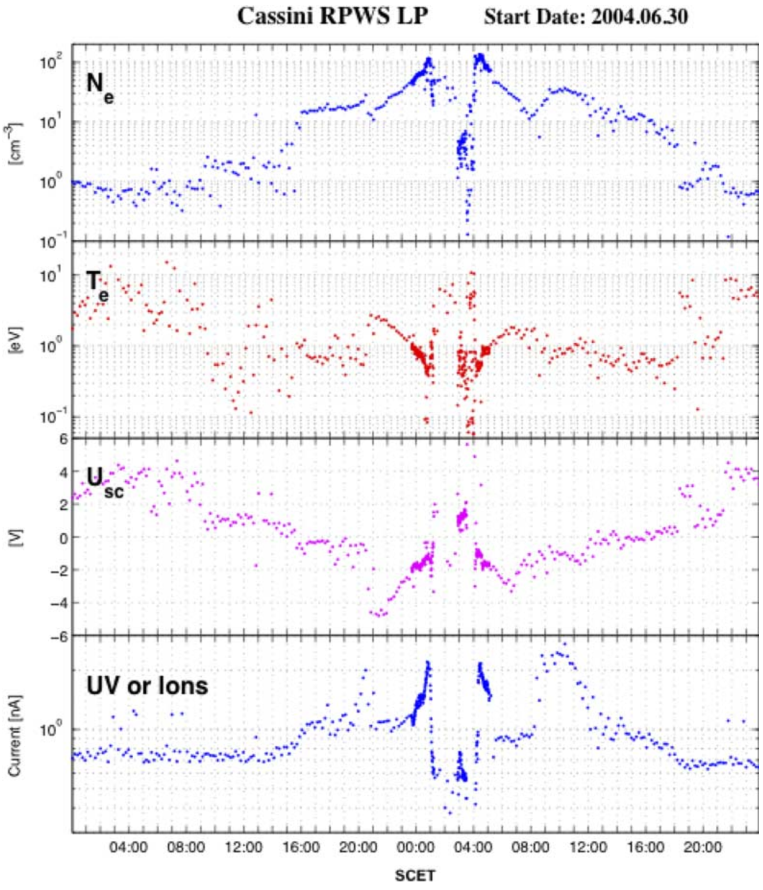


Fig. 4. Derived parameters from Cassini RPWS Langmuir probe potential sweeps during the flyby of the inner magnetosphere of Saturn. The Langmuir probe gave useful results even for densities as low as 0.1 cm^{-3}. Closest approach occurred near 03:00 SCET (UT).

interaction with the co-rotating magnetospheric plasma of Jupiter.

7.4. Plasma flow velocity and δn/n interferometry

Two Langmuir probe sensors separated by a few meters allow the determination of the plasma velocity component in the probe separation direction by a "time-of-flight" method. If plasma density fluctuations ($\delta n/n$) are sampled simultaneously at two spatially separated points, the signals will show a substantial degree of correlation, but with a time shift corresponding to a propagation velocity. This technique has successfully been used on magnetospheric satellites to study plasma flow velocities (e.g., Holmgren and Kintner, 1990). A similar method can be used to monitor the atmospheric outflow (erosion) from the icy moons caused by the eroding action of the co-rotating magnetosphere of Jupiter. An accuracy of a fraction of a km/s is achievable for relative plasma-spacecraft velocities not exceeding approximately 100 km/s.

7.5. DC electric fields and low-frequency waves

A most valuable complement to the JIMO payload would be a double-probe electric field instrument (Fahleson, 1967). These probes can in a "minimum configuration" be the same probes as those used for the density measurements described above, or they can be a separate set of probes. The basic principle is to measure the potential difference between the two probes. The corresponding electric field in the surrounding plasma is then the potential difference between the probes divided by the probe separation distance. Electric field signatures from plasma waves are sometimes also dependent on their coherence lengths (or wavelengths for linear waves) if of the same order as the probe separation.

A relatively new development for electric field measurements makes use of wire booms where the pre-amplifiers are located in a separate housing mounted on the wire boom close to the probe for increased sensitivity. Such a configuration was adopted successfully for the Cluster II mission (Gustafsson et al., 2001) and is now proposed for the BepiColombo project bound for Mercury. The instrument planned for BepiColombo also uses a newly developed boom deployment mechanism with a mass of approximately 0.5 kg for 15 m of boom wire. The mechanism is scaleable and can easily be adapted for other boom lengths. With a configuration separating the pre-amplifier housing from the probe a very sensitive electric field measurement can be obtained with a resolution down to 0.02 mV/m or better, meeting all scientific requirements. An example from the Cluster mission is shown below, more information on the BepiColombo instrument and its expected perfor-

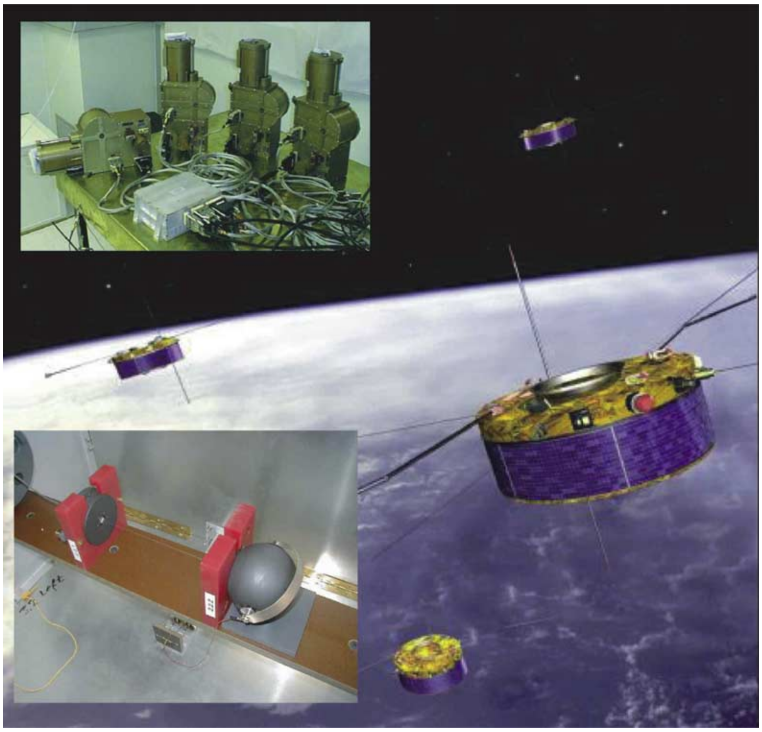


Fig. 5. Each of the four Cluster II spacecraft are equipped with four extendable wire booms up to 40 m length each. The wire boom housing (top left) and the probe and pre-amplifier housing (bottom left) are parts of the EFW instrument.

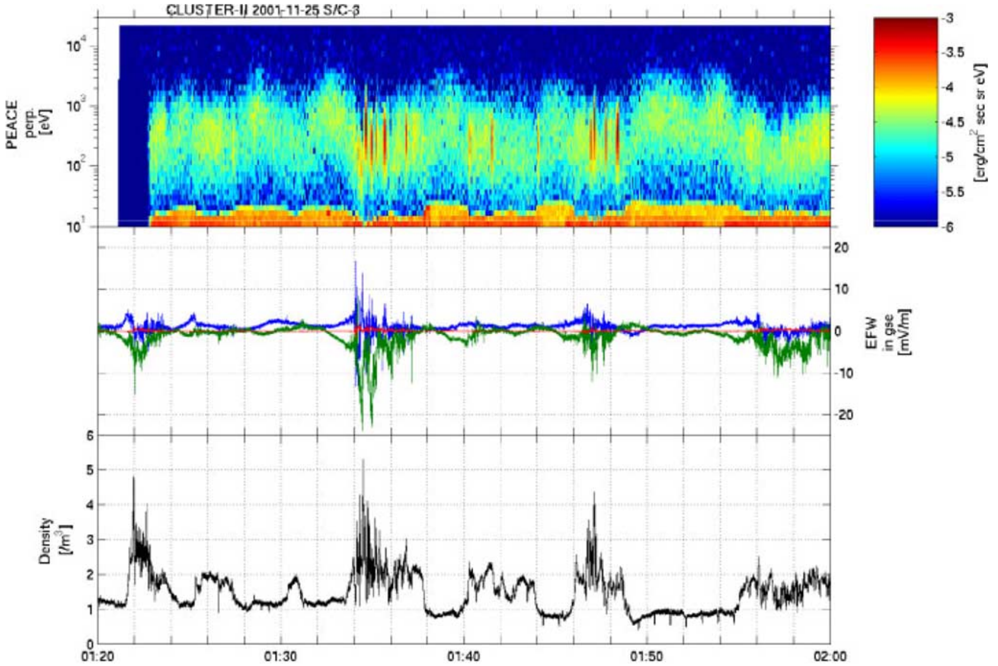


Fig. 6. An example of Cluster II electric field (panel 2) and density (panel 3) derived from probe measurements compared with electron data (panel 1). The measurements are from the Earth's magnetospheric boundary with the solar wind and shows evidence of large scale surface Alfvén waves induced by the Kelvin–Helmholtz instability.

mance is found in Blomberg et al. (2004a,b) (see Figs. 5 and Fig. 6).

8. Summary

We have shown that a double Langmuir probe, measuring the cold plasma component as well as electric fields, can significantly contribute to a number of crucial scientific objectives to be addressed by the Jupiter Icy Moons Orbiter (JIMO) project. This includes, for example, the structure, composition, variability, and origin of the ionospheres and thin atmospheres of the icy moons of Jupiter. A double Langmuir probe would provide important experimental constraints regarding the weathering properties of the icy surfaces due partly to the space radiation environment or internal volatile expulsions. Furthermore, such an instrument would provide crucial information regarding the dynamic interaction of these icy moons with the co-rotating magnetosphere of Jupiter and how this interaction feeds processes that transfer energy to other parts of the Jovian system such as the aurora near the polar regions of the planet Jupiter.

In a minimum configuration the same probes may be used for the plasma and electric field measurements. Preferably, for optimal performance, two sets of probe-pairs should be used. New developments make long electric field booms feasible also on mass constrained spinning interplanetary spacecraft.

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